

Clusters of galaxies as high-energy calibrators

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XMM-Newton / Chandra / BeppoSAX flux/temperature comparison of clusters

(J. Nevalainen, L. David et al. 2009 in prep.)

- Temperatures → shape of the total efficiency
- Flux → normalisation of the total efficiency (TBD)
- FeXXV / FeXXVI line ratio nearly independent of calibration

Clusters are good for calibration

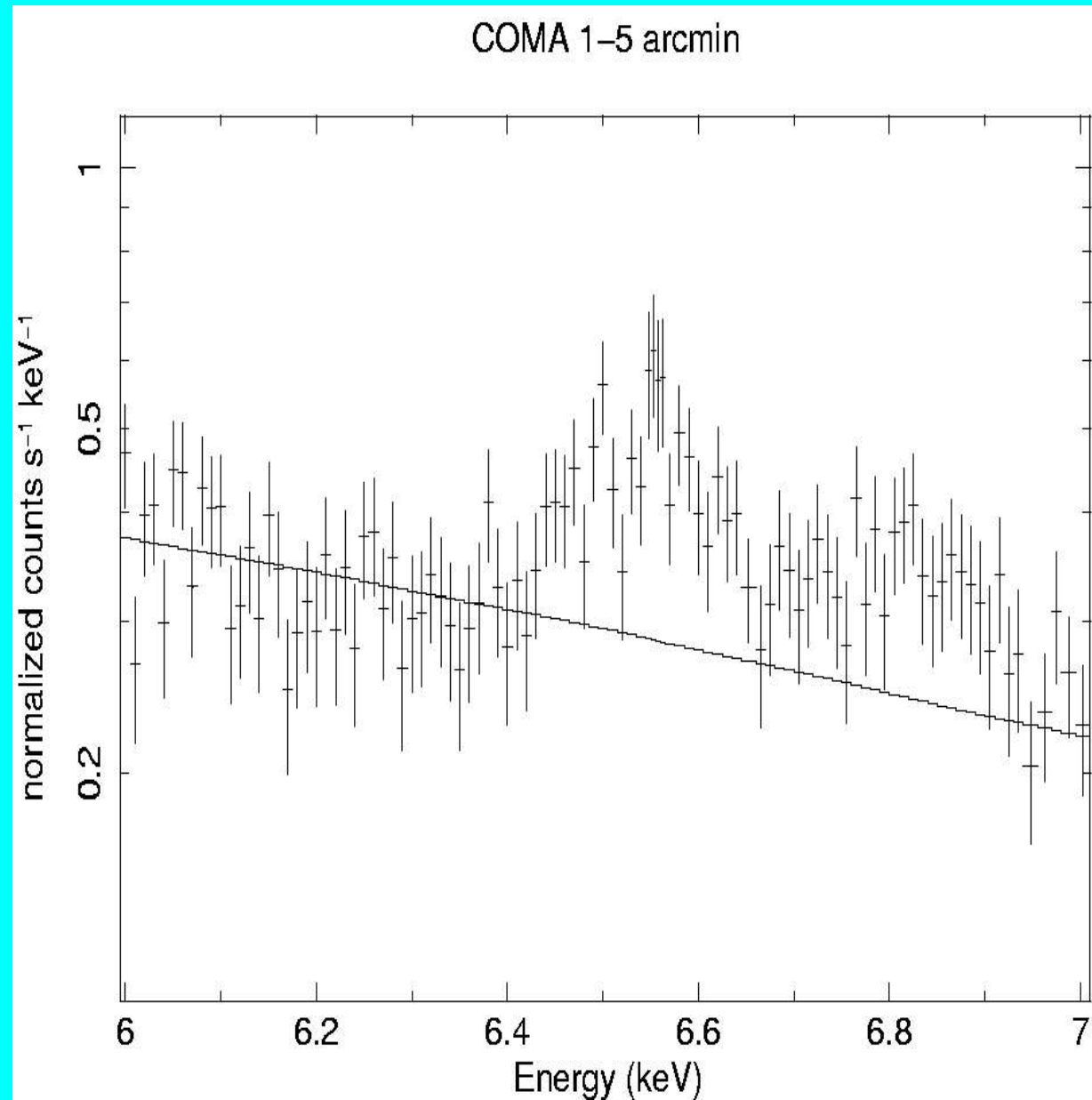
- bright (up to $L = 10^{45}$ erg/s)
- hard (up to $T=10$ keV)
- non-variable (no simultaneity requirement)

Selected clusters

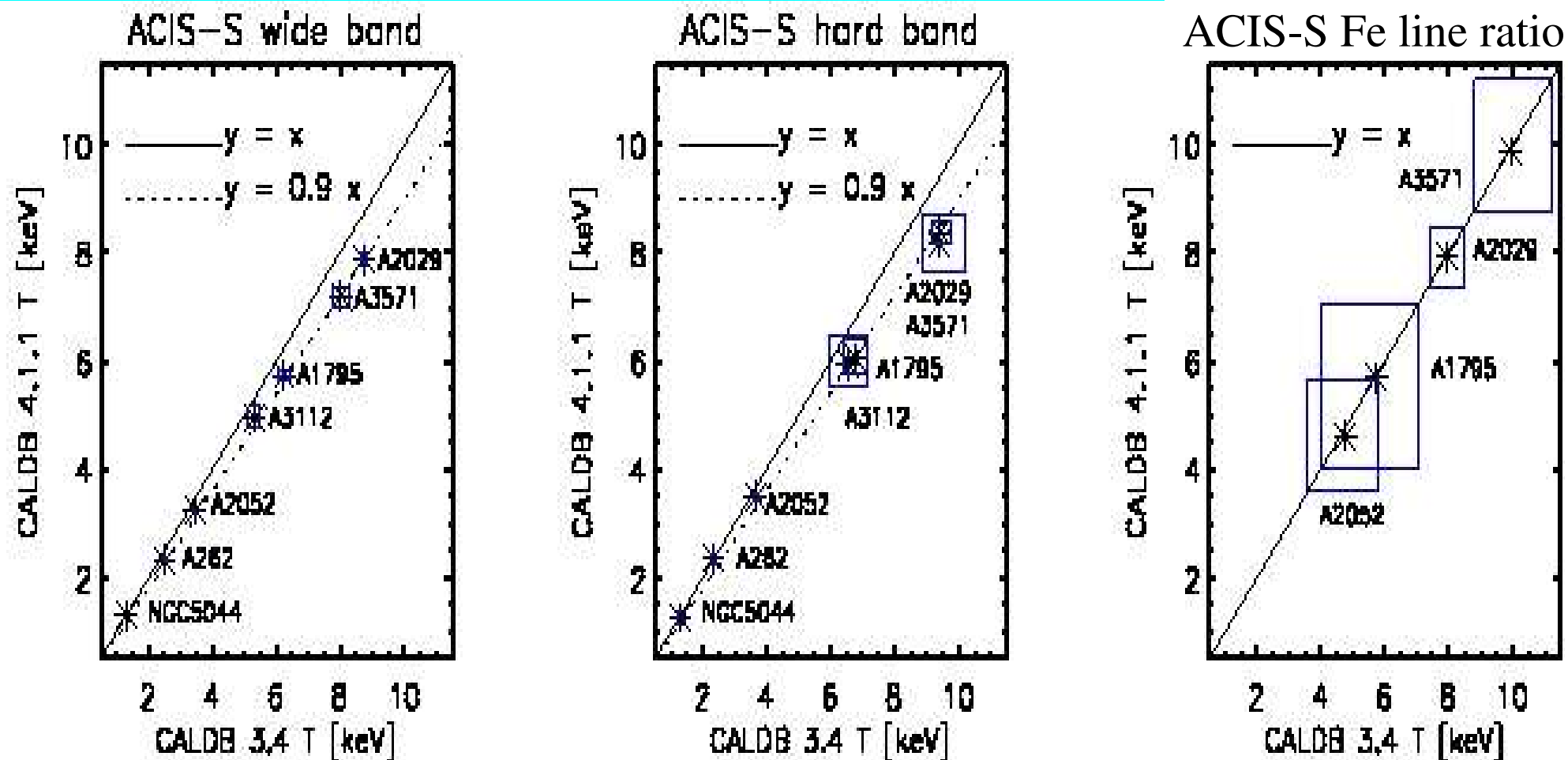
- nearby ($z < 0.08$) = bright
- relaxed (no azimuthal asymmetries in temperature and brightness)
- outside cool core (70 kpc \sim 1'-2')
- ACIS-S FOV limits the region to $r \sim 4'$
- 11 clusters: A85, A262, A1795, A2029, A2052, A2199, A3112, A3571, Coma, HydraA, NGC5044

Methods

- Single (bremsstrahlung) temperature MEKAL fit to *hard band* $\equiv 2.0 - 7.0$ keV
wide band $\equiv 0.5 - 7.0$ keV
- FeXXV / FeXXVI emission line ratio: brems + Gauss + Gauss
- change in calibration gives different continuum temperature \rightarrow
model prediction does not change in a narrow band \rightarrow
line fluxes do not change \rightarrow
line ratio T calibration independent
- (approximated here by a MEKAL fit to 6-7 keV band)

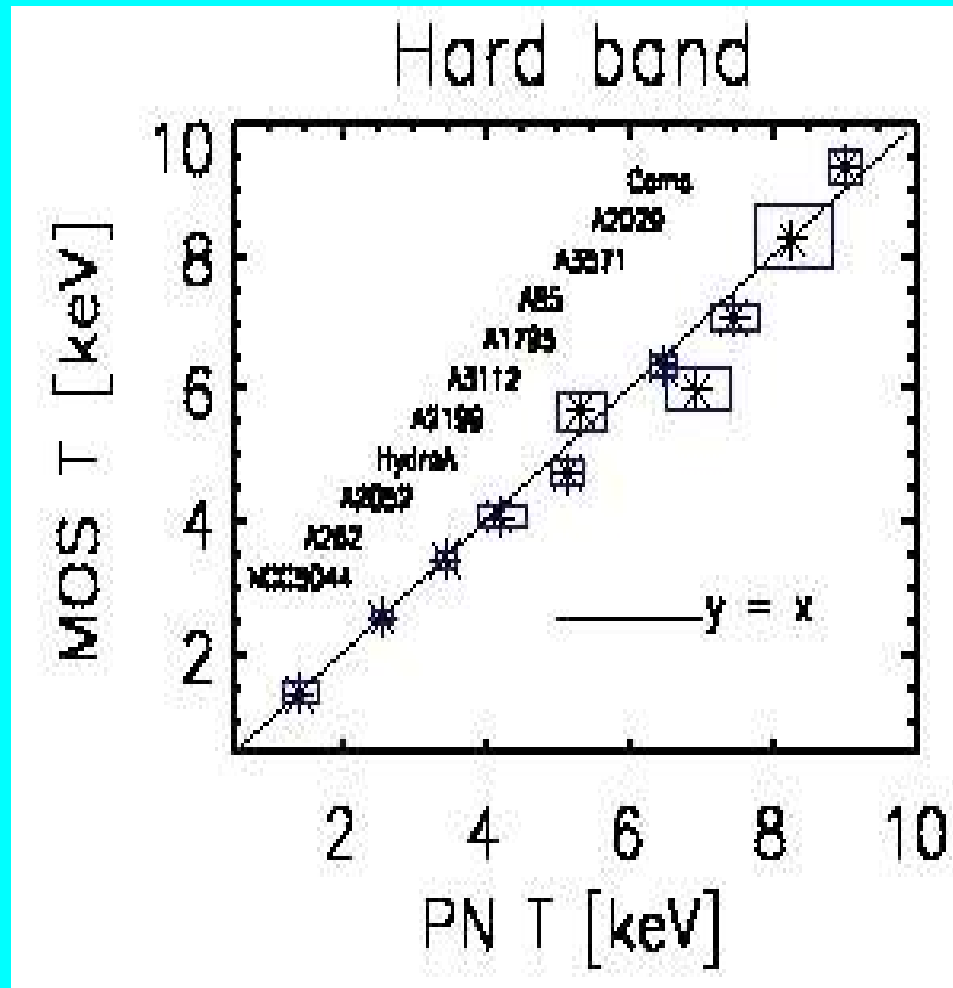


Methods



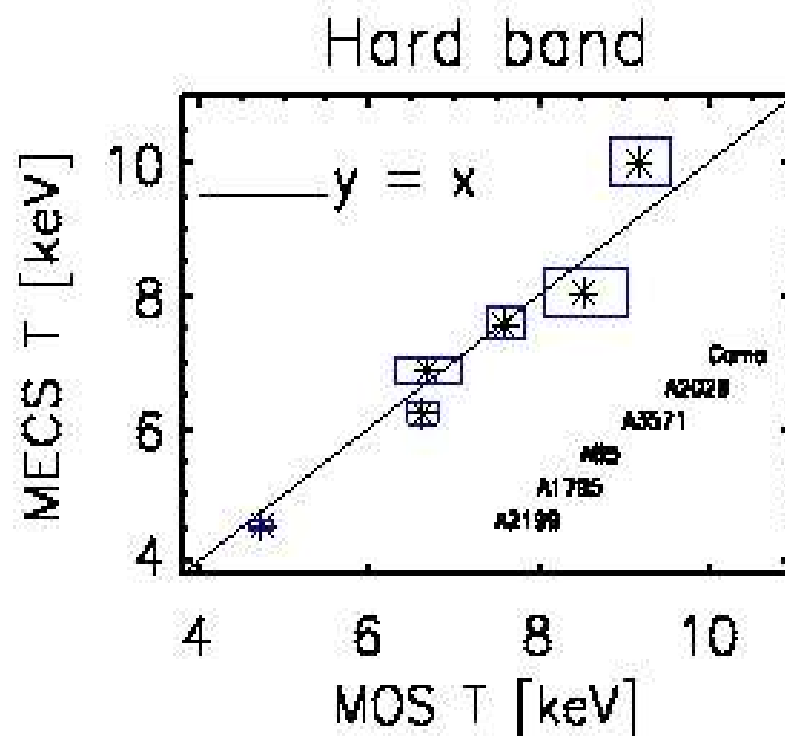
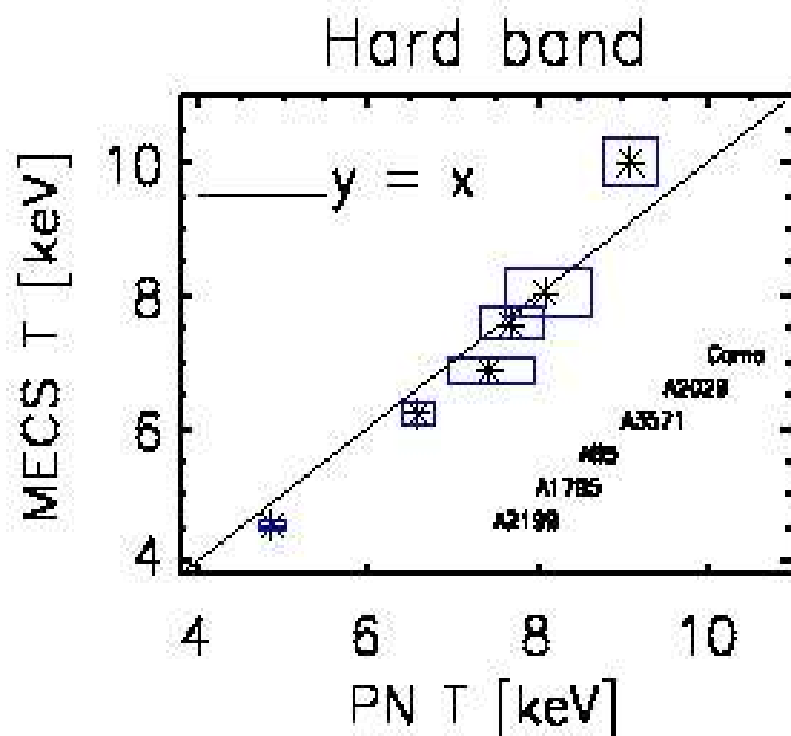
- Fe line ratio method nearly calibration-independent (could be examined more with older calib. and XMM)

PN v.s. MOS



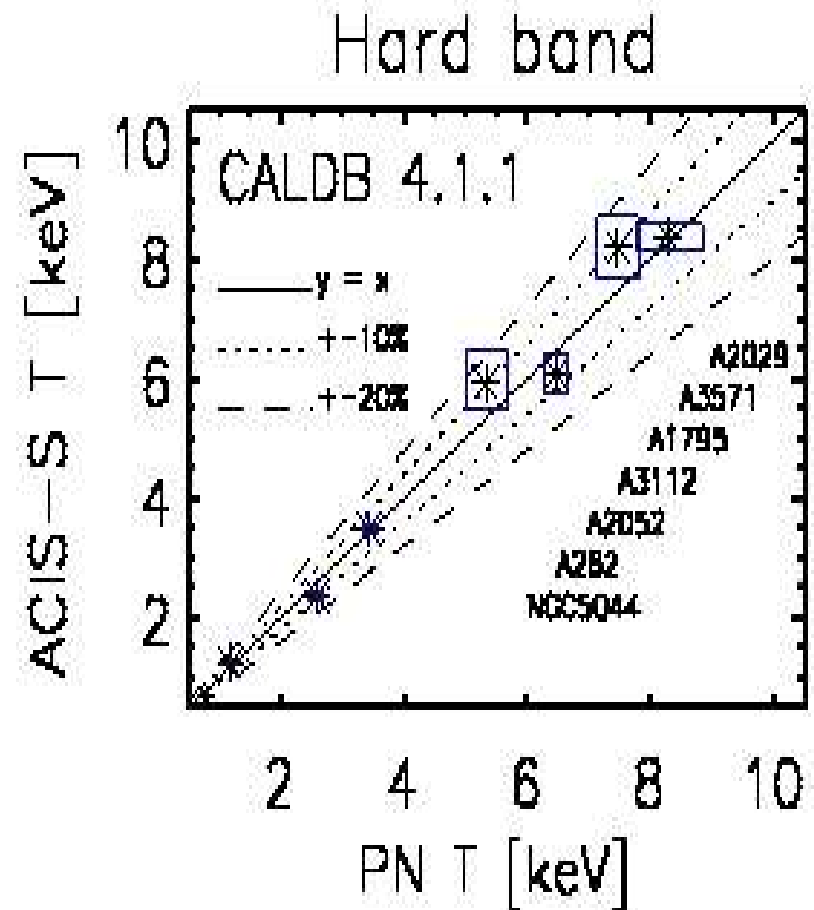
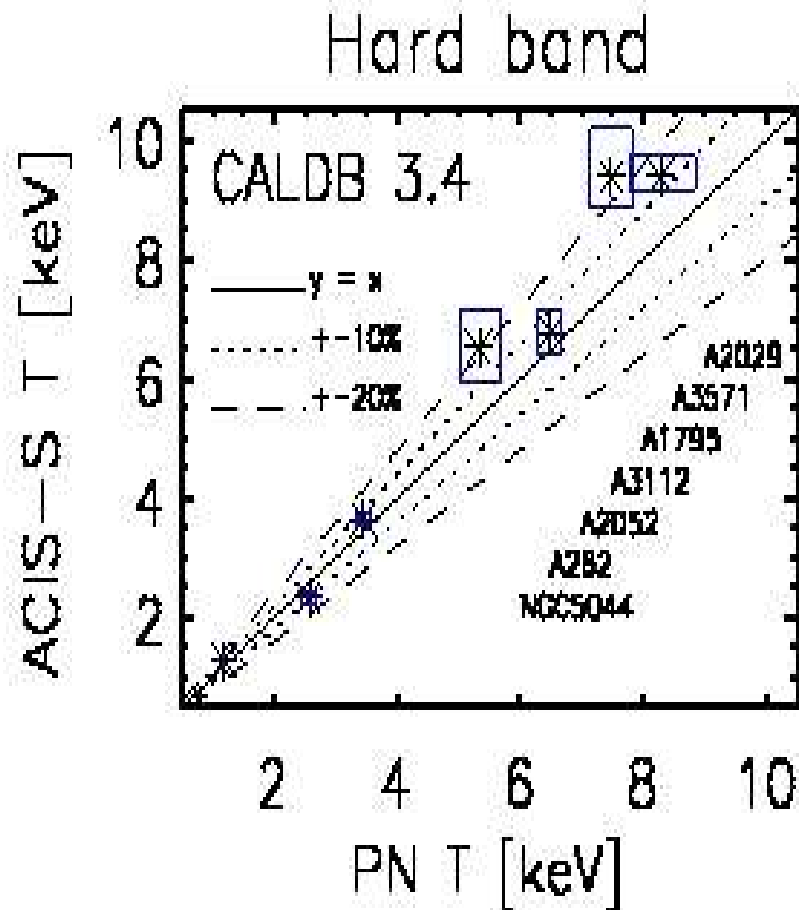
- T(hard) values consistent at 1σ CL
- as expected (PN and MOS well cross-calibrated)
- Sample values differ by 2% in average in both bands

XMM-Newton EPIC v.s. BeppoSAX MECS



- 2-4 arcmin annuli, hard band
- MECS 2-10 keV band values from (deGrandi & Molendi, 2002)
- All consistent at 1σ CL (except Coma)
- MECS temperatures systematically 3-4% lower (is this serious?)

XMM-Newton PN v.s. Chandra ACIS-S

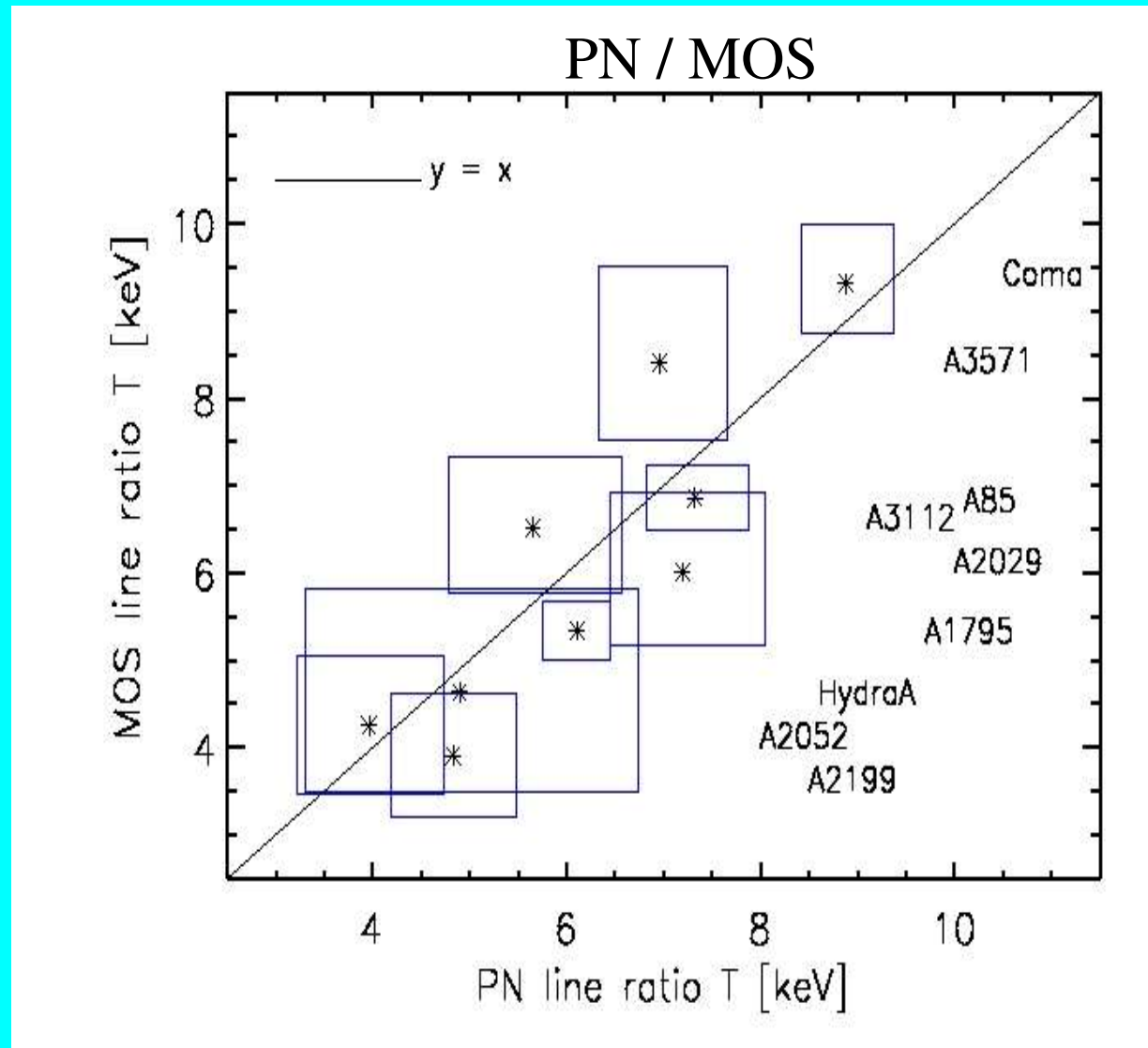


- Old calibration: $T > 4$ keV clusters inconsistent, by a maximum of 25%
- New calibration: $T(\text{hard})$ consistent at 1σ CL

Summary: hard band

- PN, MOS, MECS and ACIS-S consistent at 1σ CL
- Best-fit T of the sample between different instruments varies by less than 4% in average
- Quite unlikely that all instruments calibrated incorrectly in such a way that the derived incorrect temperatures agree
- Rather, the absolute hard band total efficiency shape calibration is correct within 4% for the above instruments

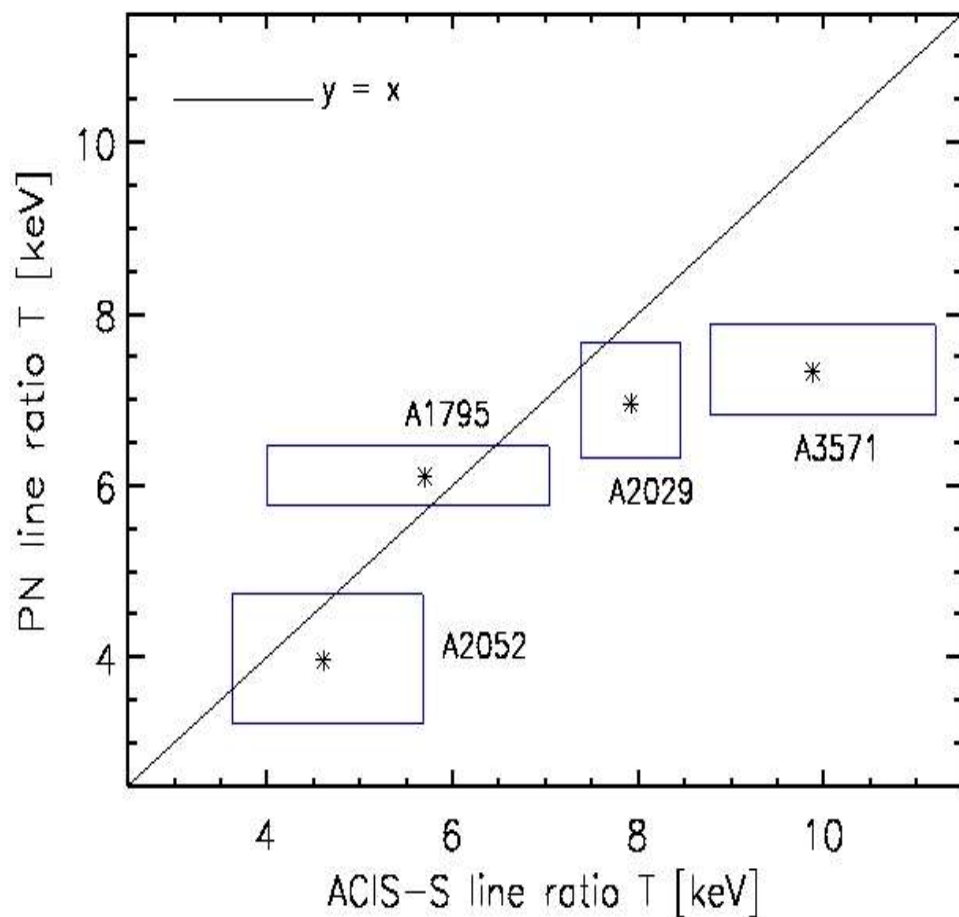
FeXXV / FeXXVI



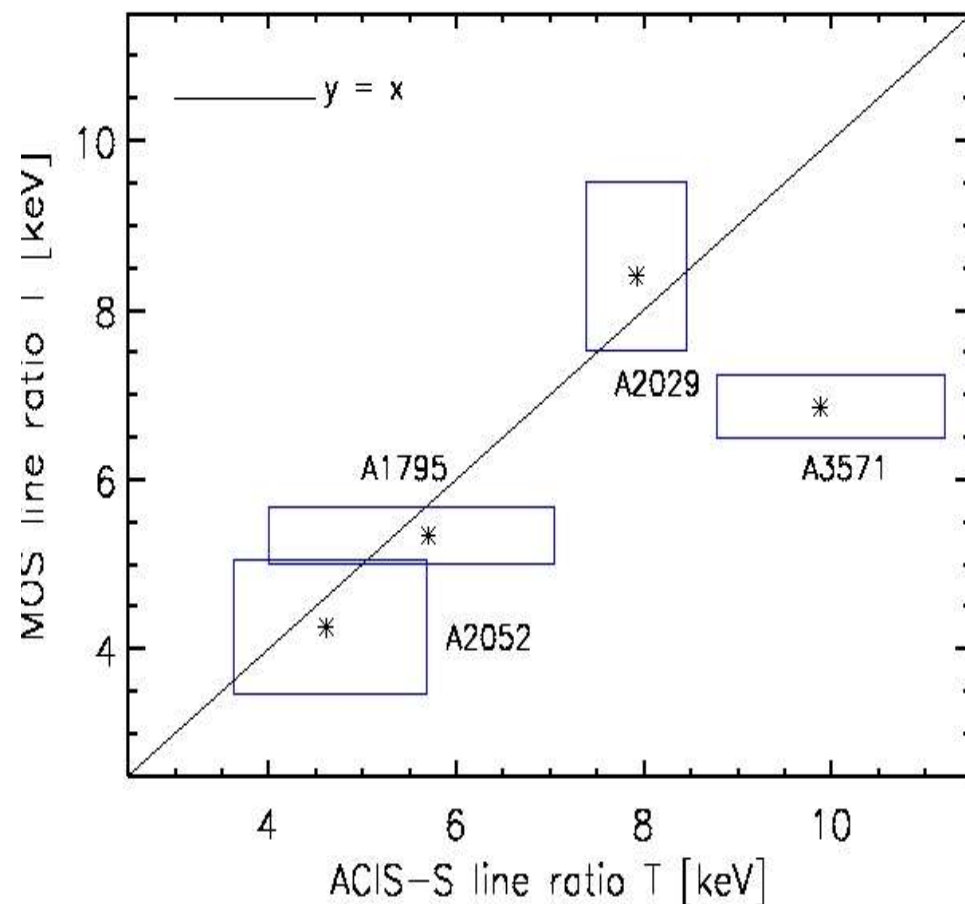
- PN and MOS T(Fe) consistent at 1σ CL

FeXXV / FeXXVI

ACIS-S / PN

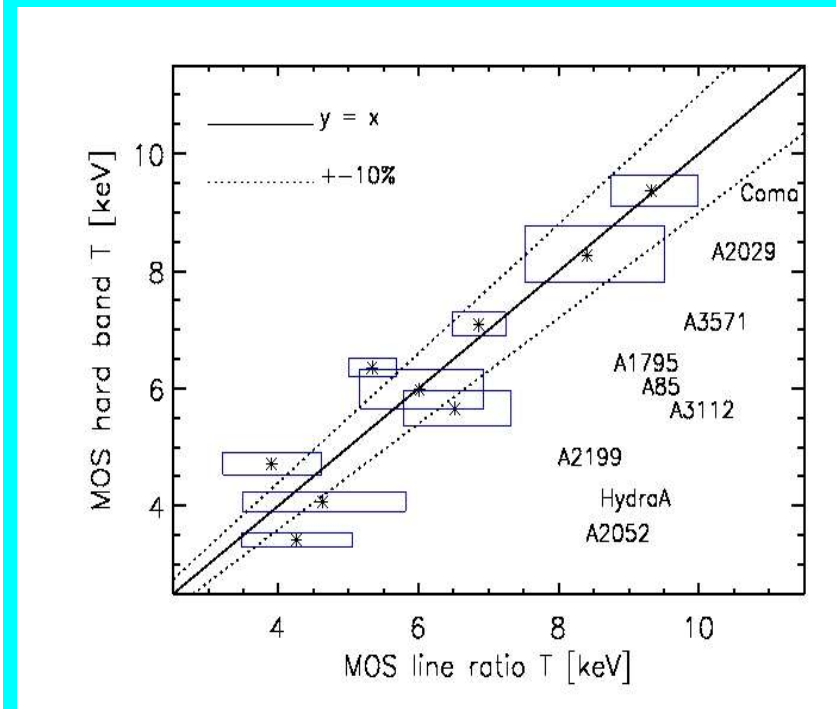
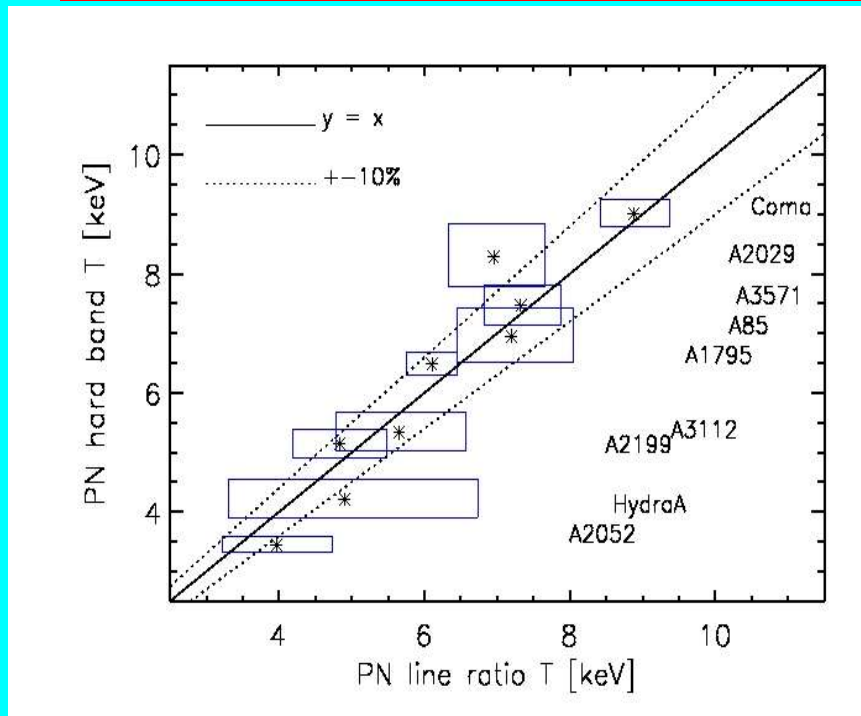


ACIS-S / MOS



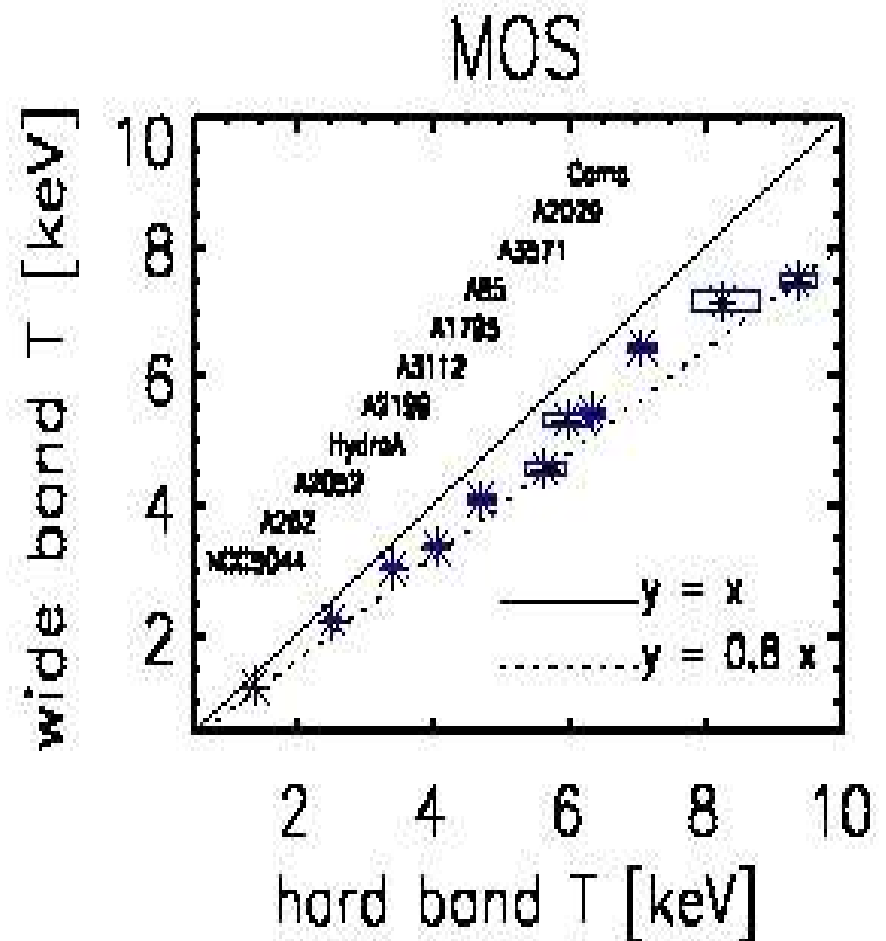
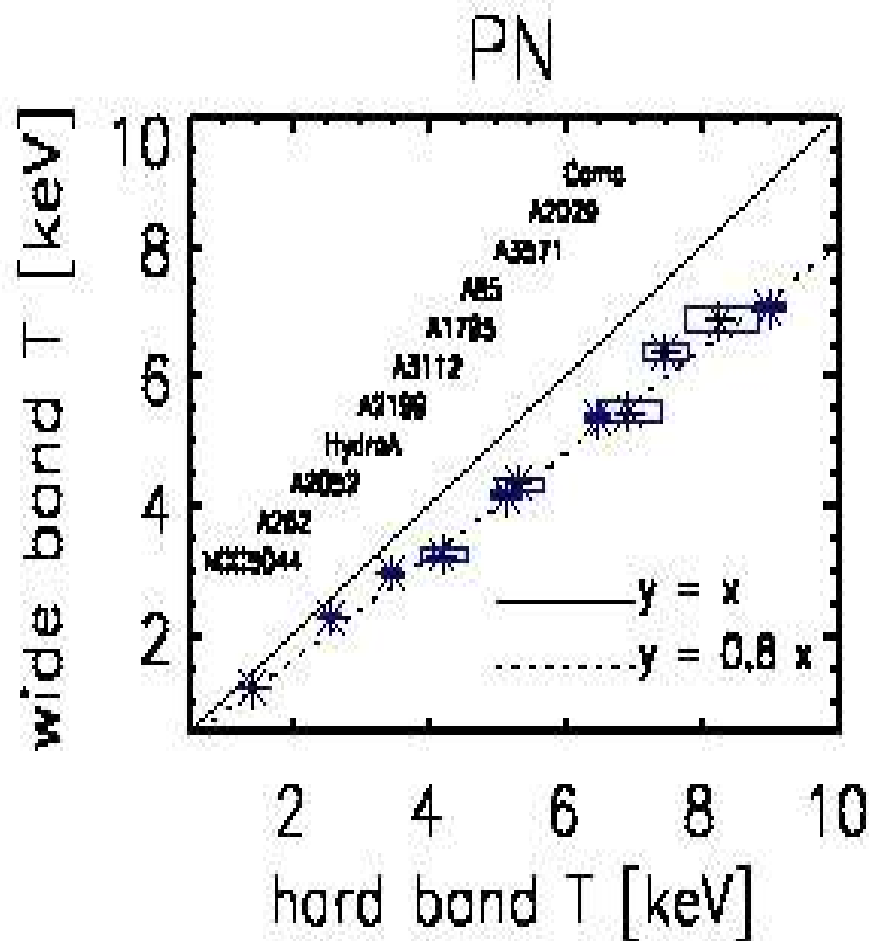
- EPIC and ACIS-S T(Fe) consistent at 1σ CL (except A3571)

FeXXV / FeXXVI v.s hard band



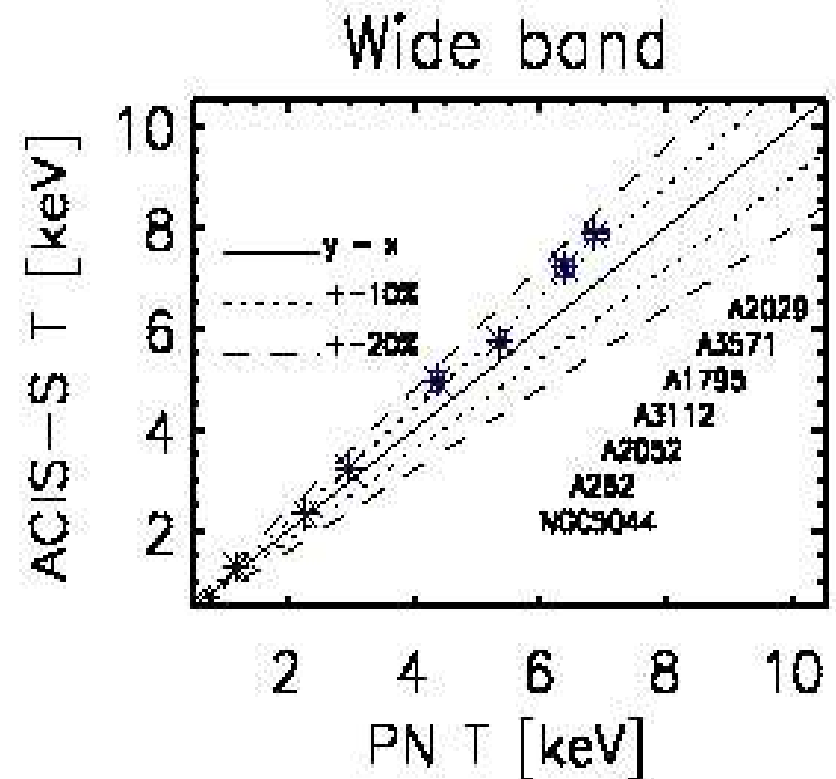
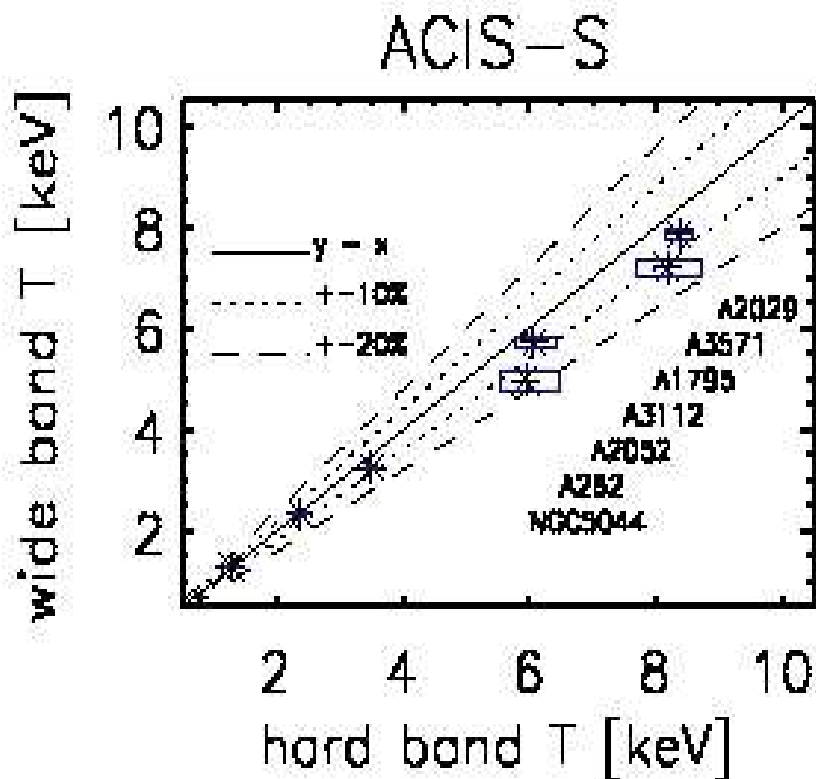
- T (Fe) and T (hard) consistent at 1σ CL (PN and MOS) (except A1795 in MOS)
- Sample values differ by less than 1% in average (PN and MOS) \rightarrow
- no room for significant non-thermal bias in 2-7 keV band \rightarrow
- FeXXV / FeXXVI ratio very useful for hard band calibration:
 - a) Measure (calibration-independent) FeXXV/FeXXVI ratio (or use our legacy? results)
 - b) Adjust the calibration so that hard band T equals the line ratio value

Wide/hard band PN v.s. MOS



- $T(\text{wide}) / T(\text{hard}) \sim 0.8 \rightarrow$ soft band calibration problems and/or soft excess emission

wide/hard band PN v.s. Chandra ACIS-S



- ACIS-S: $T(\text{wide}) / T(\text{hard}) \sim 0.9 \rightarrow$ soft band calibration problems and/or soft excess emission
- Wide band: $T(\text{ACIS-S}) / T(\text{PN}) \sim 1.1 \rightarrow$ soft band calibration problems

Summary: hard v.s. wide band

- EPIC $T(\text{wide}) / T(\text{hard}) \sim 0.8$, ACIS-S $T(\text{wide}) / T(\text{hard}) \sim 0.9 \rightarrow$ soft band calibration problems
- If ACIS-S soft band calibration is correct:
PN and MOS calibration should be fine-tuned to increase $T(\text{wide})$ by 10%, without changing $T(\text{hard})$
- If PN and MOS soft band is calibration correct :
ACIS-S calibration should be fine-tuned so that it yields 10% lower $T(\text{wide})$, without changing $T(\text{hard}) \rightarrow$
- in both cases we need something else than hydrocarbon contaminate adjustment (filter transmission, quantum efficiency?)
- how do other calibration works see this issue?

Summary: hard v.s. wide band

- T(hard) and T(wide) disagree in all instruments (PN, MOS and ACIS-S) →
- we need additional soft X-ray emission (WHIM, cool gas clumps, non-thermal IC from CMB)
- Catch 22: clusters not useful for $E < 2$ keV calibration, until the additional emission can be measured accurately and this requires accurate calibration